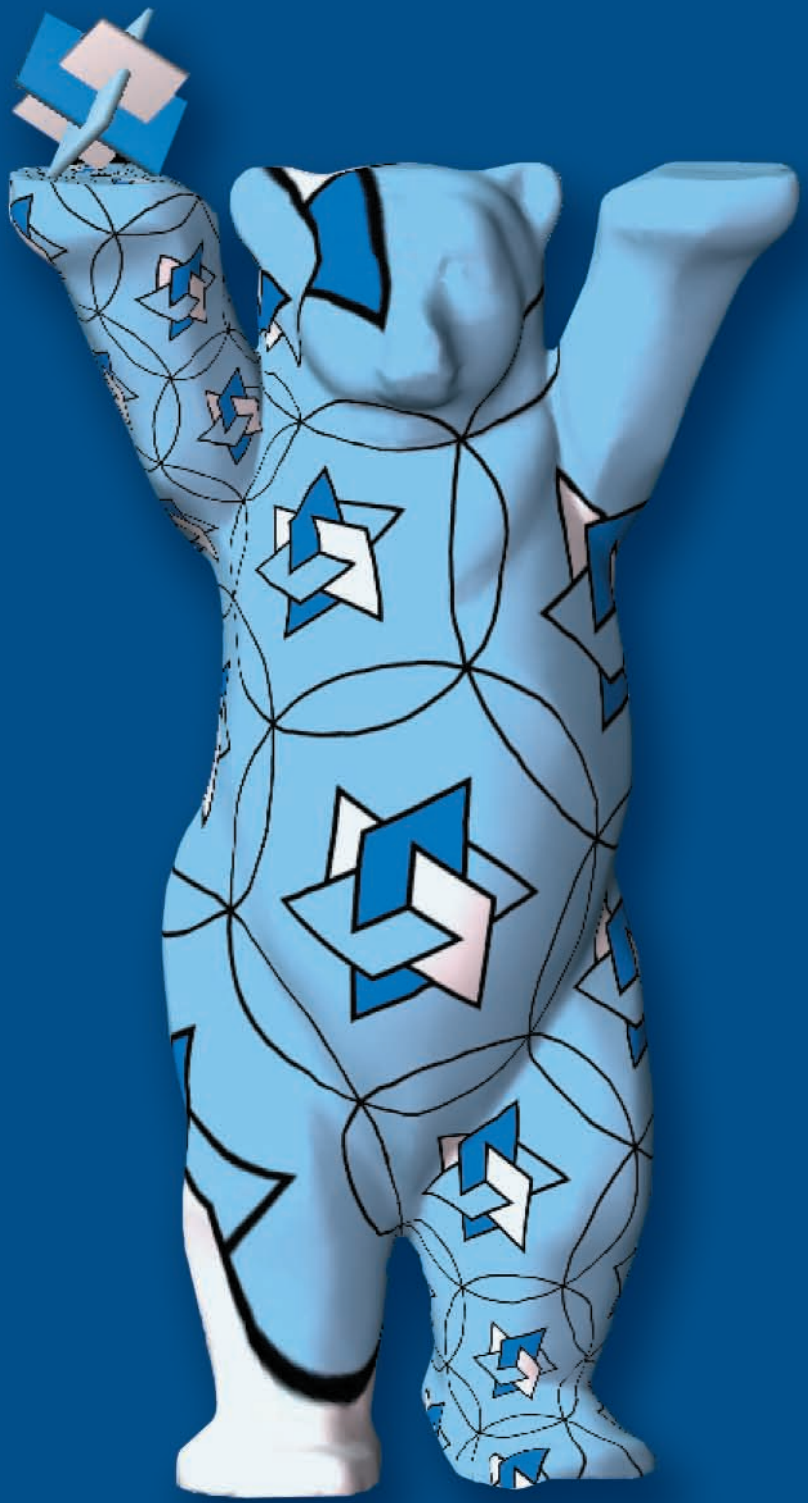
MATHEON

Mathematics is the Future

DFG Research Center MATHEON
Mathematics for Key Technologies



Creative and Efficient

Mathematics is creative. Mathematics is exciting and multifaceted. Mathematics is the future. Without mathematics, modern key technologies would be unimaginable. In fact, without mathematics, the entire universe would most likely remain a complete mystery to us.

The DFG Research Center MATHEON was established in 2002 as a means by which mathematics could be used to help increase the efficiency of technological developments. The center is run by the mathematics departments at Berlin's three major universities – the Technical University, the Free University and Humboldt University – as well as by the Zuse Institute Berlin (ZIB) and the Weierstrass Institute for Applied Analysis and Stochastics (WIAS). With the support of the German Research Foundation (DFG), MATHEON aims to develop tailored solutions for the complex problems of modern key technologies.

MATHEON's primary fields of application are life sciences, traffic and telecommunications networks and logistics, production, circuit simulation and opto-electronic devices, finance and visualization. Scientists at MATHEON are involved in about 70 projects aimed at finding solutions for basic mathematical problems in each of these fields. The approximately 200 scientists model, simulate and optimize real-world processes using methods taken from the mathematical sub-fields of discrete mathematics, optimization, numerical analysis, scientific computing, as well as applied and stochastic analysis.

True to its motto "Mathematics is the Future", MATHEON works to promote the intrinsic fascination of mathematics. The project's target groups are the wider public and particularly schools. A number of projects aim to show students how fun and interesting mathematics can be. Such projects include the Mathematical Advent Calendar, the MATHEredaktiON school newspaper project as well as numerous lectures and workshops.

MATHEON's high level of scientific excellence has received worldwide recognition. More and more companies are coming to depend on the know-how of the center's mathematicians when looking for solutions to the widest range of questions. The creativity and efficacy of the research activities conducted at MATHEON have consistently won over its partners in business and industry.

www.matheon.de


Dräger Sola
Segmentierung

Counting on a Cure

Diabetes, cancer and Creutzfeldt-Jacob disease are examples of illnesses that – either directly or indirectly – affect large numbers of people. In many cases, these diseases can still not be cured because they are based on very complicated processes, which to this day are not completely understood. Nevertheless, in recent decades, enormous advances have been made, many of which were made possible by the use of mathematical methods.

Mathematics has assumed a significant role in many branches of the life sciences, such as in the development of new medications, therapies and cures. MATHEON's "Life Sciences" research area testifies to the growing importance of this field. Its research activities make it possible for important biological and medical processes to be mathematically modeled, tested in virtual laboratories, adapted and optimized.

Projects in the "Life Sciences" application area are engaged in developing new medications and planning their targeted effects. Research on the characteristics of particular molecules is simultaneously conducted with the analysis of molecular networks. This work, in turn, sets the foundations for the development of mathematical tools for the modeling of cellular and physiological processes in systems biology and pharmacokinetics.

Additional projects in the "Life Sciences" research field are devoted to computer-assisted surgery planning, which allow for the comparison of various options before the actual operation on the basis of a simulation of increasingly detailed and realistic models of soft tissue, bone and human movements. A further topic in the field of computer-assisted medicine is the search for entirely new perspectives for the optimal design of prostheses adapted to individual anatomy.

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Networks for an Organized World

We encounter networks everyday and everywhere. Tightly interwoven street, bus, railway and airline networks form the backbone of local and global mobility, and logistical networks lay the groundwork for efficient production and the reliable supply of goods. Without high-capacity communications networks and transferring data, it would be impossible to surf the Internet or even make a phone call. Countless factors influence and affect the quality, costs and safety of these networks. Traditional approaches to planning no longer suffice when attempting to grasp complex interrelations nor when seeking optimal solutions to problems that arise.

World-class experts involved in MATHEON's "Logistics, Traffic and Telecommunications Networks" application area develop mathematical methods for modeling, simulation, optimizing and controlling complicated flows of materials, people, energy, financial transactions and information. The goal of these methods is to make decisions – out of the almost infinite range of possibilities – that maximize the benefits for clients. Among the methods applied and further developed are linear, integral and stochastic optimization, graph theory and combinatorics. Our success – and that which has been achieved as a result of cooperating with several industry partners – is reflected in the fact that our research is followed around the world.

MATHEON's current projects include planning the network for UMTS cellular phones and developing the best design for the landline telephone network of Germany's National Research and Education Network (DFN-Verein). The time-table for Berlin's subway system was also optimized here, along with personnel scheduling for bus drivers and the commuter railway system in the capital as well as in many other regions. Work schedules for the "golden angels" of the ADAC, Germany's emergency roadside assistance company, as well as the route plans for automated transportation vehicles in the container terminal of Hamburg's port have also been calculated using algorithms originally from MATHEON. Before long, the elevator that takes you to the floor you want with the least waiting time possible will also be controlled by an algorithm developed at MATHEON.

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Optimierung unter Unsicherheit
$\max \mathbb{E}(\langle c,x\rangle + \langle q(\xi),y\rangle :$
$Wy = h(\xi) - T(\xi)y, y \in Y\}$
ξ - zufällige Preise und Last
ξ_i - Szenarien

Efficient Production Thanks to Mathematics

Production processes in modern key technologies, such as semiconductor engineering, photovoltaics and medical engineering, are becoming more and more complex. Moreover, new materials are now making previously impossible functions feasible. Real challenges have arisen as a result of the need to control complicated steps in development, production and processing. A major contribution to meeting these challenges has been made by the methods of mathematical modeling, simulation and optimization.

MATHEON's "Production" application area concentrates especially on multifunctional materials but also on important aspects of electricity generation.

Modern steel plays a central role in a number of studies. Owing to its material properties, more and more demands are being made on steel to serve as the base material for numerous industrial applications.

These demands can only be met if scientists can comprehend and control the phase transitions encountered in the production and processing stages, such as the changes in physical properties under varying heat conditions. Our mathematical methods also help these processes to be implemented in concrete industrial applications, such as in computer-guided lasers and welding robots.

An additional area of research entails the mathematical modeling and simulation of shape memory alloys. Even after considerable deformation, objects made from these materials are able to "remember" their original shape and, under certain conditions, reform themselves into their original shape. A few sample applications for shape memory alloys include those in modern engines, sensors and medical stents.

Semiconductor materials play a crucial role in producing both chips and solar cells used to generate power. The modeling and production processes for semiconductors represent another focus of MATHEON. For example, a method for growing semiconductor crystals using gallium arsenide (GaAs) has been modeled, simulated and optimized here. Other researchers focus on thin liquid film, drop deposition and the effect of light on semiconductor processes, which are very important, for example, for the production of modern solar cells.

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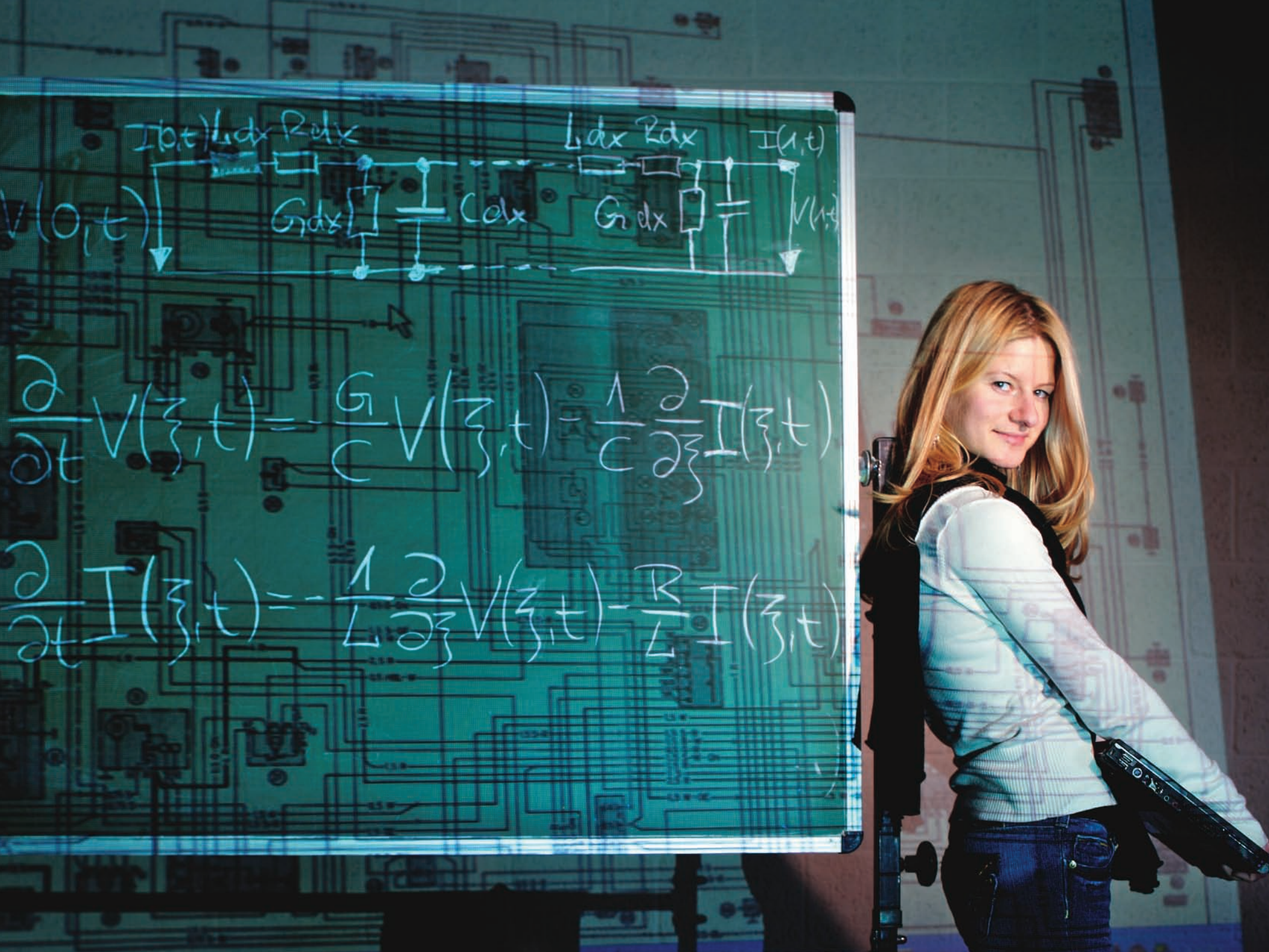
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Mathematics for the Chips of Tomorrow

The invention of the transistor, laser and microchip were milestones in the history of technical progress. Along with ever more powerful computer processors, these inventions have revolutionized our everyday lives. At the same time, integrated circuits are becoming more and more complex; the components used in transistors are getting smaller and smaller; production cycles are growing shorter and shorter; and the technical aspects of putting things into production are getting more and more complex. In addition to electricity, light is also coming to play an increasingly important role in technical applications, for example, in solar cells, lasers and fiber optic lines.

For many years, mathematical modeling and numerical simulation have been successfully employed in electrical technological developments. However, to a growing extent, these established methods have been reaching their limits. As a result of advances in miniaturization and new applications, physical effects that up to now were either not encountered or played absolutely no role at all must now be understood and mastered. The constantly growing complexity of products also necessitates new mathematical approaches.

The scientists at MATHEON working in the "Circuit Simulation and Opto-Electronic Devices" application area are committed to meeting these new challenges.

A number of research projects are focused on quickly and reliably simulating the three-dimensional diffusion of electromagnetic waves. These play an important role, for example, in the development of new nano-optical components, such as miniature lasers and new generations of solar cells. An equally important research topic is the delineating and simulating of optical systems using quantum mechanical models.

Another important research focus involves the modeling and numerical simulation of increasingly more complicated integrated circuits for new generations of chips by means of so-called algebraic differential equations. This type of equation is also used to delineate and electronically control complicated systems, such as modern automotive transmissions, in the best way possible.

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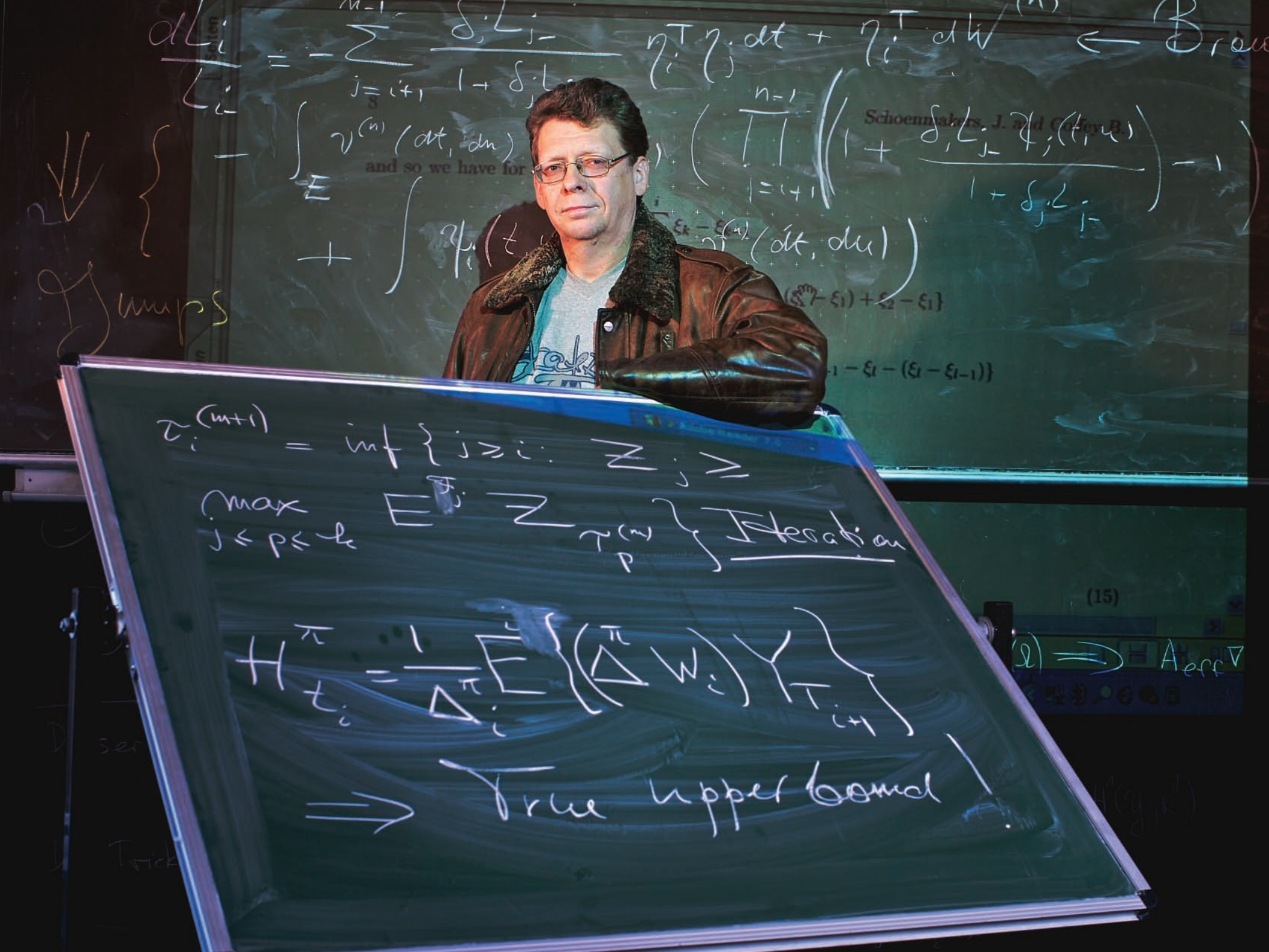
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Limiting Risks

The world of finance is getting more and more complex. New derivatives capture the market, hedging becomes more and more important, and the interdependence between global and local markets increases. For banks and the insurance industry, risk factors such as climate change and rising raw materials costs are increasingly important. The standard textbook models no longer suffice to explain financial markets.

One result is the increasing demand for mathematical solutions. Methods based on probability theory and statistics are more and more often being used to analyze financial risks in their various guises. This has led MATHEON's "Finance" research division to undertake various research projects using mathematical modeling, simulation and optimization. For many years now, Berlin and MATHEON's "Finance" applications area, in particular, have played a leading role in this field.

Mathematicians at MATHEON study pricing processes for goods being traded on different markets. They are also researching safety measures while taking into consideration risk factors associated with changes in weather and climate.

MATHEON plays a leading role in the search for dynamic investment strategies with the optimal criteria for minimizing risk.

Lastly, for the general evaluation of economic instruments and their associated financial risks, scientists at MATHEON determine new statistical and numerical mathematical methods using high-dimensional models, and they develop effective algorithms as well.

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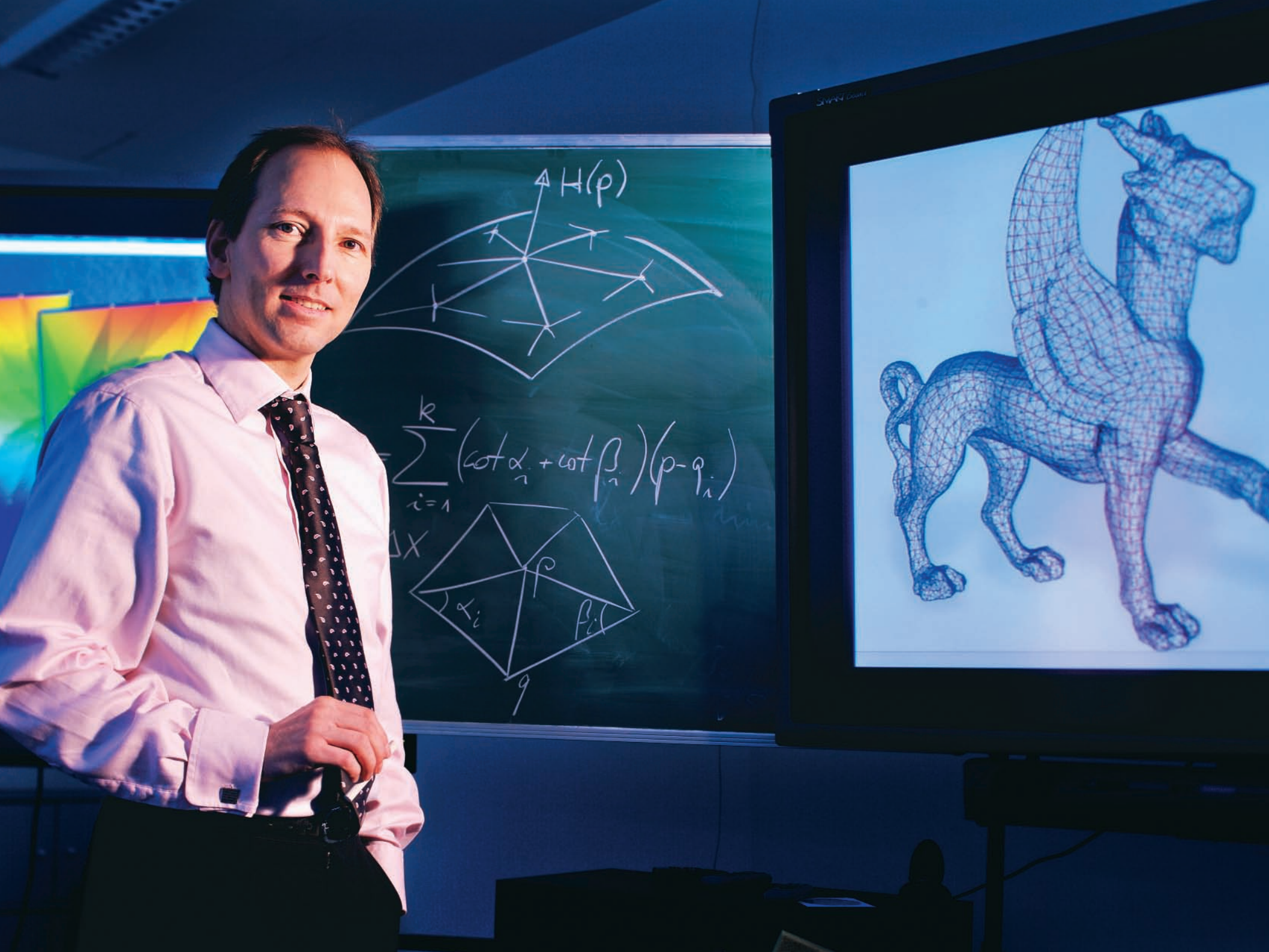
H(p)
$\sum_{i=1}^{k} (\cot \alpha_i + \cot \beta_i)(p - q_i)$
α_i
β_i
p
q

Virtual Imaging

Today, the calculations involved in the observation of scientific and technological processes or in measuring and imaging procedures are producing increasingly complex and comprehensive forms of data. And yet, people are not able to directly access the information contained in these calculations and techniques. The data only becomes accessible once it has been processed, filtered and visualized in a form people are used to. Visualization is also necessary and helpful when it comes to electronically diagramming or manipulating complex 3-D objects. Whether for diagramming free-form architecture, designing new automobile bodies using CAD, or creating realistic computer animation for films, new mathematical methods of describing and processing objects on a computer have become basic prerequisites.

The researchers in MATHEON's "Visualization" research field develop efficient algorithms for the visual analysis of large amounts of data. When it comes to transferring "old" geometry into a computerized form, i.e., "discrete geometry", our scientists number among the world's leading experts. In its widest sense, discrete geometry analyzes the interplay between 3-D objects and their computerized representations. In doing so, it plays a supporting role in the processing and optimization of polyhedric forms in industrial applications, such as CAD and computer graphics. Multistage algorithms are also developed for industrial applications and computer graphics for which large surface networks must be efficiently processed. These algorithms are in particular demand in the automotive industry.

In addition, the results of the work conducted at MATHEON are also used in producing computer games and large films.

Image segmentation, i.e., the detection and identification of objects using existing anatomical knowledge, is the basis for applications in computer-aided therapy and operation planning. New methods are also being developed for visualizing quantum molecular systems occurring in chemistry and physics.

Lastly, MATHEON's 3-D portal makes mathematical visualization possible and permits the experimental diagramming of curvilinear spaces and the examination of geometric optimizing functions in biophysics and material sciences.

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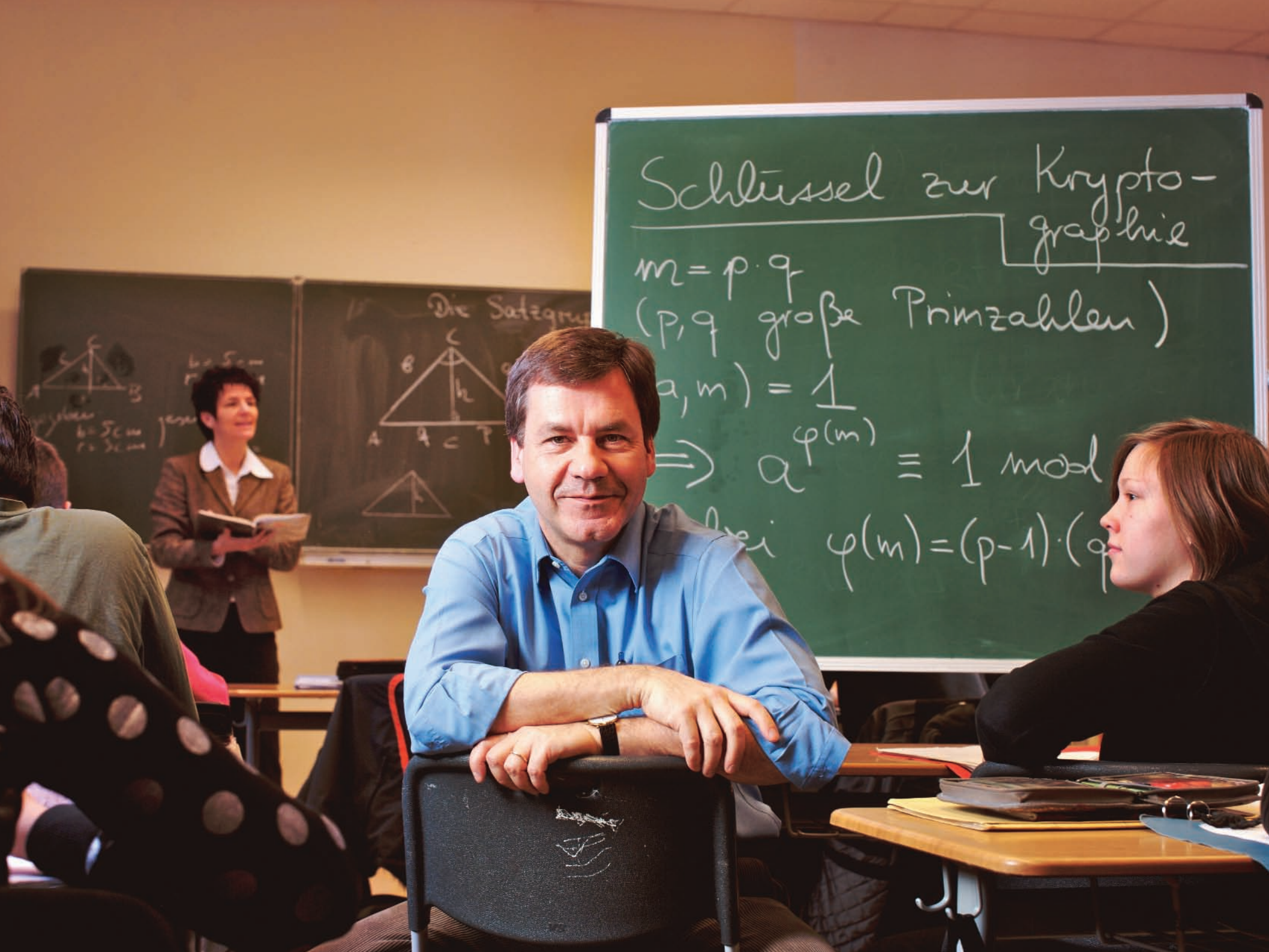
Schlüssel zur Kryptographie
m = p · q
(p, q große Primzahlen)
a, m) = 1
⟹ a^φ(m) ≡ 1 mod
φ(m) = (p-1) · (q

Improving Mathematics Education

Mathematical education in Germany was under scrutiny even before the first PISA study was undertaken. The study did not give particularly good grades to German students, and the educational system was criticized as well. Large numbers of students still have the preconception that mathematics is boring, incomprehensible and pointless. The readiness of a certain segment of teachers to rebut this prejudice by bringing excitement and diversity to their classrooms is another element that could be addressed in the future.

In order to improve this situation, MATHEON has introduced an "Education" application area. Scientists in this field strive to develop new concepts for educating teachers. MATHEON is also involved in advanced and continuing education and uses the practical experience of three teachers in its project's ongoing work. Berlin's Senate Department for Education, Science and Research has delegated each of these teachers to MATHEON for a year to aid in this research. In the context of Berlin's network of schools with high reputations in mathematics and natural sciences, the participating teachers and scientists are also involved in programs supporting gifted students.

New teaching and learning materials are also developed and tested at MATHEON. New content development and models for classroom teaching as well as teaching plans are also compiled. Colleagues participate in a diverse array of commissions, with the goal of integrating the vitality and versatility of mathematics into everyday classroom life and teaching plans.

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MathInside
April:
Mai?: Uranie
1.-12.: Mathekalender

Awakening Student Interest

MATHEON has initiated a range of projects aimed at getting students interested in and enthusiastic about mathematics as early as possible. In cooperation with mathematics teachers, MATHEON organizes project weeks at Berlin schools during which games are used to introduce students in the fifth and sixth grades to mathematical topics. At the same time, these project weeks provide teachers with new ideas for integrating practical, real-life applications into their teaching.

Each year, older students meet for a week outside Berlin for a summer school program called "Feeling like Math", where they work on exciting mathematical subjects under the supervision of MATHEON scientists.

A series of lectures under the motto "MathInside" is held for students at Urania Berlin three times each school year. All schools in Berlin and Brandenburg are invited to the lectures delivered by MATHEON members. MATHEON also offers a selection of tours and lectures to school groups from all over Germany and abroad. The "Rent the Center" program also offers a catalogue of mathematics-related lectures, which schools can book for specific groups or classes.

The MATHEredatiON program brings together journalists from school newspapers five times a year at participating institutes to conduct research and interview scientists, after which they can go on to compose articles to be published in their school newspapers.

One of the annual highlights of MATHEON's school activities is the Digital Advent Calendar. Every day from December 1 to 24, young people are invited to solve a new tricky mathematical problem posted on the Internet, and a number of valuable industry-sponsored prizes can be won. Each year, nearly 10.000 students and adults and a growing number of people from all over the world participate in this "math calendar."

www.matheon.de/schools


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& Versicherungen
Transport
Elektronik

Mathematics is the Mother of Invention

Mathematicians are famous for seeking out "problems" – the more complex, the more exciting. And what could be more complex than reality, especially when it involves new developments in modern key technologies? For this reason, the scientists at MATHEON are always searching for new mathematical challenges arising from industrial and business practices. Industry and business, in turn, are increasingly employing mathematics to structure and transfer complex problems into technical, quantitative models. Mathematical approaches allow problems to be better understood, to recognize what is essential, to make predictions in difficult situations and to make better decisions.

MATHEON offers industries its internationally recognized expertise in the complete spectrum of applied mathematics. Moreover, MATHEON provides access to a worldwide network of excellent contacts in the research areas of mathematics, computer science, the natural sciences, economics, engineering and medicine.

In recent years, MATHEON's offerings have convinced over 100 companies from Germany and abroad to cooperate with MATHEON scientists in applied research projects, many of which have led to innovative solutions in various industries. For example, MATHEON scientists have filed a number of patents and have developed software that is being used profitably in industry and business. Several mathematical methods and concepts have been and are being further developed in a series of companies founded to bring them to maturity and then professionally market them.

MATHEON organizes regular workshops for industry and business so as to be able to sound out the potential for mathematical solution-finding approaches in ongoing projects in industrial research and development. Special seminars are used to communicate the current state of mathematical research "in a user-friendly way". Moreover, MATHEON makes great efforts to provide the next generation with excellent, application-oriented qualifications in the fields of both engineering and mathematics.

www.matheon.de/transfer

MATHEON is actively engaged in finding innovative solutions in a number of fields including the following:

- Architecture & Construction Industries
- Automotive Engineering & Machine Manufacturing
- Banking & Insurance
- Electronic & Semiconductor Industries
- Energy & Water Supply
- Logistics
- Media & Entertainment
- Medical Engineering
- Pharmaceuticals
- Processing Industries
- Telecommunications
- Transport & Traffic

A selection of our numerous projects conducted in cooperation with partners in business and industry can be found on the Internet.

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www.matheon.de/transfer

MATHEON
Media and Public Relations

MATHEON's press office is the point of contact for both journalists and interested members of the public. The office promotes the fascinating world of mathematics and supplies the public with whatever information they may need. Its many activities include (but are not limited to!) arranging for experts to speak on various issues, organizing visits to either of its 3-D projection rooms and its 3-D laboratory, arranging discussions with scientists, and organizing exciting lectures. If you sign up for our mailing list, we will send you the current press releases. You can also subscribe to our newsletter, which appears on an irregular basis. Furthermore, all other MATHEON publications can be procured from the press office, which is also available to help with images, films and other visual media. MATHEON's press office also confers an annual media prize open to young journalists for the best print article on mathematics and its applications.

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www.matheon.de/press

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